Determination of Canine Dose Conversion Factors in Mixed Neutron and Gamma Radiation Fields

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Armed Forces Radiobiology Research Institute | Technical Report 96-2

July 1996

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Foreword

The primary objective of mixed-field neutron/gamma radiation dosimetry in canine irradiation experiments using the AFRRI reactor is to accurately determine the absorbed dose delivered to the region of interest in the canine. For whole-body irradiation experiments, the point at which this dose is measured is the midabdomen region, thus called the midline tissue (MLT) dose.

An estimate of the MLT dose can be obtained from the dose delivered to a phantom—a substitute object that will mimic and approximate dose distribution in the canine. In general, the closer the phantom mimics the canine, the better the approximation. For this reason, efforts have been made at different laboratories to construct detailed and often lifelike phantoms. Ideally, to facilitate comparisons with different laboratories doing similar studies, these phantoms should be identical.

For correlation with the biological endpoint, complete information on dose distribution of both neutrons and gamma rays in the canine is required. Such data is not easy to obtain and certainly will be different for different laboratories. Again, these radiation measurement problems are approached by estimating the MLT dose delivered to the region of interest.

This report is a summary of the measured dose conversion factors (DCFs) that were used to determine the MLT doses in canines at AFRRI from 1979 to 1992. The quality of such measurements made in a laboratory and the variations in measurements made in different laboratories will reflect the type and positioning of phantoms used.

Henry M. Gerstenberg
Chief, Operational Dosimetry Division

Contents

Introduction

The Armed Forces Radiobiology Research Institute (AFRRI) conducts radiobiological research using a variety of nonhuman mammalian species to predict the effects of ionizing radiation on man. One aspect of the study is to determine the relative biological effectiveness (RBE) of a given radiation dose in producing a well-defined effect. RBE is defined as the ratio of an x- or gamma-ray dose to that of the radiation in question, resulting in the same kind and degree of biological effect (1). The RBE depends on the biological endpoint studied, the dose, the dose rate, and the preexisting physiological condition of the subject. In the canine irradiation experiments conducted at AFRRI, the biological endpoints of interest have been bone marrow death and gastrointestinal death resulting from whole-body doses; thus, the median lethal dose values $LD_{50/30}$ and $LD_{50/6}$, respectively, are the quantities of interest.

Whole-body doses in AFRRI experiments are quoted in terms of midline tissue (MLT) doses as recommended by the International Commission on Radiation Units and Measurements (ICRU) (2). Since 1979, canine MLT doses have been determined by applying a dose conversion factor (DCF) to a dose measurement made free in air (FIA). The DCF is determined by taking the ratio of two measurements. The first measurement is the MLT dose rate taken at a well-defined midline point within a phantom. The second measurement is made by removing the phantom and taking an FIA tissue dose-rate measurement at a convenient point in the region occupied earlier by the phantom. The tissue-air ratio (TAR) commonly used in radiotherapy is a special case of DCF when both of these measurements are made at the same point in space (3). Once determined for a particular experimental setup, the DCF value is applied to all future FIA measurements to obtain the MLT dose rate using exactly the same setup.

In 1979, AFRRI began measuring canine DCFs by using canine cadavers as well as appropriate canine phantoms. DCF values are dependent on the choice of phantom and the point at which the MLT and FIA dose-rate measurements are made. This report summarizes the various canine DCF measurements made through 1992.

Methods

Ionization Chambers

Radiation dosimetry in the mixed neutron and gamma radiation fields was performed at AFRRI by concurrently using two ionization chambers made of different wall materials (4-6). This method is often referred to as the paired-chamber technique. One chamber has approximately the same sensitivity to both gamma rays and neutrons. The other chamber is sensitive to gamma rays but has a low sensitivity to neutrons. The first chamber is constructed of tissue-equivalent (TE) plastic (type A-150) and is filled with TE gas (64.4% methane, 32.4% carbon dioxide, and 3.2% nitrogen, by volume). The second chamber is constructed of magnesium and filled with argon gas. Both of these chambers, manufactured by Exradin of Lockport, Illinois, have an active volume of 0.5 ml and a wall thickness of 1 mm.

Using the paired-chamber technique, the separate neutron and gamma-ray dose rates in the mixed field can be determined if certain radiation spectrum-dependent coefficients are known for each chamber. These coefficients are discussed in appendix A.

Shielding Configuration

The DCF measurements for canine irradiations were conducted in exposure room one (ER1) of the AFRRI TRIGA reactor facility (TRIGA is an acronym for training, research, isotope, General Atomic). The reactor core is suspended under approximately 4.9 meters of water (7). A 15-cm lead shield is placed in front of the tank wall with the reactor core positioned as close as possible (within 2.54 cm) to the tank wall. That position places the center of the core at 30 cm from the tank wall. Wooden planks impregnated with boron (borated wood) were placed along the sides of the tank wall. Figure 1 shows the shielding configuration used in ER1; figure 2 shows the lead and borated wood shielding around the tank wall.

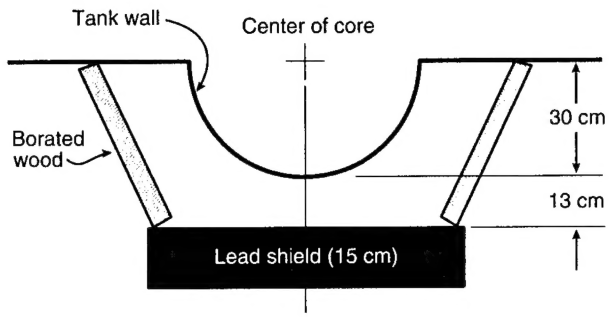

Fig. 1. Shielding configuration for neutron field.

With this shielding configuration, a radiation field with a large neutron dose component (approximately 90% of the total FIA dose) was obtained. Much of the gamma radiation emanating from the core into the exposure room was attenuated by the lead. The neutron and gamma spectra for this shielding configuration are discussed in two Defense Nuclear Agency reports, DNA 5793F-1 and DNA 5793F-2 (8, 9). The average fluence-weighted neutron energy was reported to be 0.96 MeV for this experimental arrangement (10).

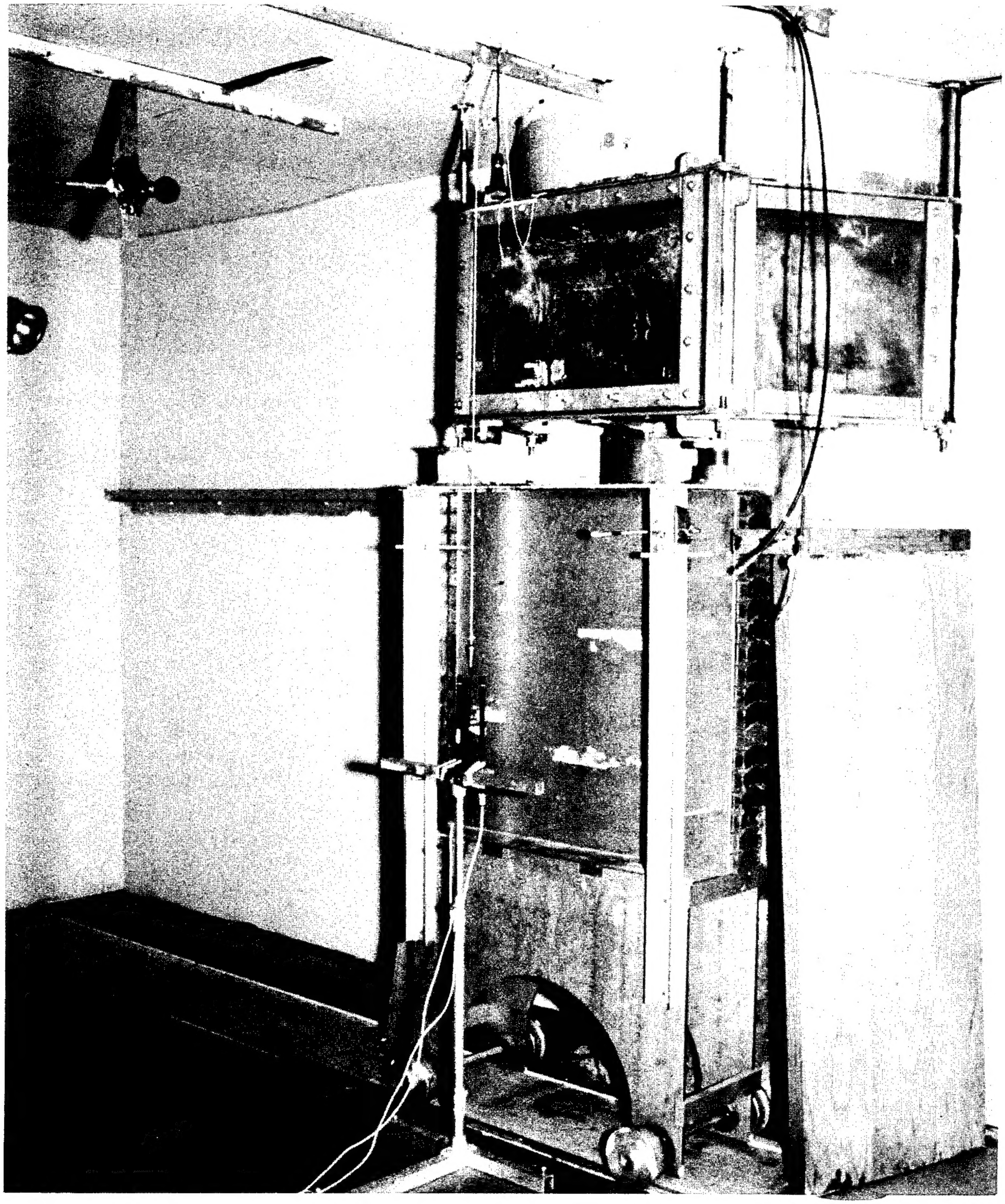

Fig. 2. Exposure Room 1 with lead shield (15-cm) and borated wood.

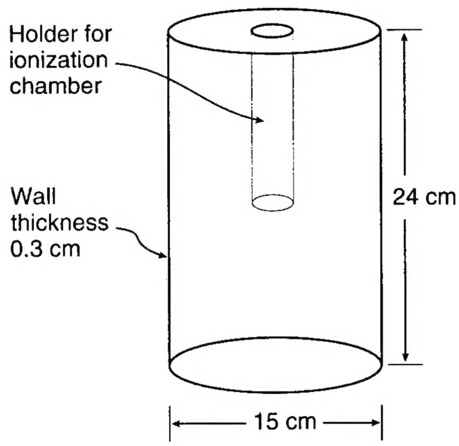

Fig. 3. Cylindrical phantom filled with TE liquid.

Phantoms

Much of radiobiology dosimetry involves the use of phantoms in which the animal shape and biological tissue composition are approximated. For the canine DCF studies, phantoms were designed to simulate a muscle tissue dose response in order to estimate the MLT dose.

The earliest phantom used by AFRRI was a hollow cylinder (figure 3) made of lucite and filled with a TE liquid composed of several major elements found in tissue and having a density of 1.06 g/cm^3. The height of the cylinder was 24 cm; the diameter of the cylinder, based on the estimated chest size of the average beagle used in experiments, was 15.0 cm. Appendix B compares the elemental composition of the TE liquid used at AFRRI and the ICRU-recommended TE liquid (without sucrose) (6). Though the composition affects neutron and gamma attenuation and scattering, the slight difference in composition between the two TE liquids should not measurably differ in the dose response of the ionization chamber placed at midpoint of the TE-filled phantom.

In 1979 the canine DCFs were determined by making ion chamber measurements, both FIA and MLT (the midpoint of the TE cylinder) at 1.00 m from the reactor core center (i.e., 0.70 m from the tank wall protrusion) and at a height of 1.20 m above the floor. In addition to the cylindrical phantom, canine cadavers were also used in the DCF measurements. Because the cadavers were of varying sizes, their DCF values ranged from 0.40 to 0.64 in comparison to 0.49 for the cylindrical phantom (see table 1). The ion chamber measurements were taken at the midline of a cadaver from a position near the last rib in the lower chest region.

In 1984, canine DCFs were determined using the cylindrical phantom as well as two additional phantoms made of TE plastic. The phantom that mimicked a dog standing on its feet was purchased from Alderson Research Laboratories, Stamford, Conn.,

Table 1. Canine irradiation values in a mixed neutron-gamma field.

Phantom	DCF	D_n/D_T FIA	D_n/D_T MLT
1979			
Cylindrical phantom* Midline	0.49	0.89	0.52
Cadavers*	0.40-0.64	0.89	0.50-0.68
1984			
Cylindrical phantom* Midline	0.48	0.92	0.66
TNO phantom**			
Midthorax	0.78	0.84	0.74
Midabdomen	0.58	0.84	0.63
AFRRI phantom**			
Head	0.49	0.84	0.58
Midthorax	0.72	0.84	0.68
Midabdomen	0.72	0.84	0.68
1989			
AFRRI phantom** Midabdomen	0.72	0.85	0.68
1991			
AFRRI phantom** Midabdomen	0.72	0.83	0.66
1992			
Cylindrical phantom** Midline	0.50	0.91	0.67
AFRRI phantom**			
Head	0.50	0.89	0.61
Midthorax	0.68	0.89	0.64
Midabdomen	0.71	0.89	0.65

*Point of measurement: 70 cm from tank wall.
**Point of measurement: 101 cm from tank wall.

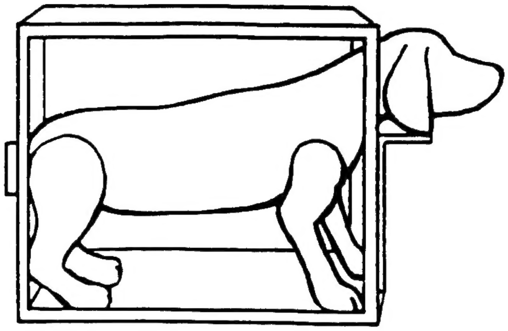

Fig. 4. AFRRI phantom.

and is referred to as the AFRRI phantom. The other phantom loaned to AFRRI by The Netherlands Organization (TNO) Radiological Research Institute in Rijswijk, Netherlands, had the appearance of a dog lying on its back with its limbs partially amputated. Figures 4 and 5 are sketches of the AFRRI and TNO phantoms.

Both the AFRRI and TNO phantoms had contoured body masses containing real canine skeletons and simulated lung tissues. The AFRRI phantom was made of Rando™ plastic (Alderson soft tissue, Alderson Research Laboratories, Stamford, Conn.) with an effective atomic number (Z_{eff}) of 7.3 and a mass density (ρ) of 0.985 g/cm^3. The lung material was made of a rigid microcellular plastic foam (Alderson lung) with $Z_{eff} = 7.3$ and $\rho = 0.32$ g/cm^3 (11). The TNO phantom was made of polyester with $\rho = 1.05$ g/cm^3, and the lungs were made of compressed cork. The type of polyester used in the TNO phantom was not specified.

The AFRRI phantom consisted of 32 individually numbered, 2.54-cm-thick transverse sections held together by a Lucite rod. Sections with holes for positioning ionization chambers (at mid-line) were the head, midthorax, midabdomen, and pelvis regions (sections 6, 18, 22, 27). Ionization chambers could also be placed to the right and left sides of the midabdomen at 1-cm depths.

Table 2. Canine phantom dimensions.

Dimension	AFRRI phantom	TNO phantom
Weight (kg)	10.2	11.1
Length (cm)		
Nose to buttocks	73.0	68.0
Shoulder to shoulder	37.0	40.0
Lateral width (cm)		
Skull	11.0	10.6
Neck	8.0	8.5
Front shoulder	12.0	13.0
Midthorax	15.0	13.6
Last rib	15.0	14.7
Midabdomen	13.5	13.8
Pelvis	12.0	13.0
Dorsal-ventral height (cm)		
Skull	11.0	9.5
Neck	10.5	9.2
Front shoulder	18.0	11.9
Midthorax	16.0	17.4
Last rib	15.5	14.3
Midabdomen	15.0	12.4
Pelvis	14.0	11.3

In contrast, the TNO phantom had no separating sections. Two holes were drilled laterally through the phantom near the midthorax and the midabdomen regions to allow placement of ionization chambers for depth-dose measurements. Table 2 lists the dimensions of the AFRRI and TNO phantoms.

Measurements were taken at several points within both the AFRRI and TNO phantoms. The midlines of the phantoms were placed at a distance of 1.01 m from the tank wall (1.31 m from the reactor core center). The points of measurement in the AFRRI phantom were at midline in the head, midthorax, and midabdomen. Only two regions, the midthorax and midabdomen, were measured in the TNO phantom.

The three phantoms were positioned differently in the radiation field. The cylindrical phantom was

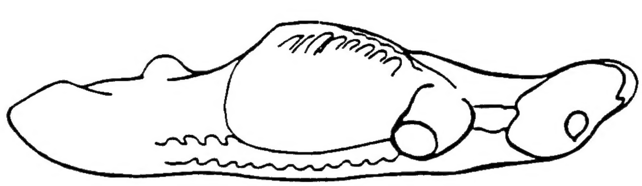

Fig. 5. TNO phantom.

placed in an upright position as shown in figure 3. The AFRRI phantom was in a normal standing position (figure 4), while the TNO phantom was in a supine position (figure 5). Prior to 1984, canines were placed in the radiation field in sitting, standing, or lying positions. After 1984, they were always placed in a standing position similar to the AFRRI phantom rather than the supine position of the TNO phantom.

Canine/Phantom Holders

Rectangular Lucite holders (cages) of 0.64-cm wall thickness, similar to the one shown in figure 4, were used to support a canine in a standing position allowing for free head movement. During dosimetry measurements, phantoms were also housed in these Lucite holders for the purpose of reproducing experimental conditions in dosimetry.

Results

In 1979, the DCF for the midpoint of the cylindrical phantom was measured to be 0.49. This value was used for all subsequent canine irradiations until 1984 when the DCFs were measured again using three phantoms. The new measured value for the cylindrical phantom was 0.48, and the DCFs for the midabdomen region of the TNO and AFRRI phantoms were found to be 0.58 and 0.72, respectively.

In 1989, 1991, and 1992, more measurements were made using the midabdomen of the AFRRI phantom as the point of reference. The respective DCF values for these years were determined to be 0.72, 0.72, and 0.71. This is consistent with the value 0.72 determined in 1984. Also in 1992 the midline DCF of the cylindrical phantom was remeasured and determined to be 0.50. Table 1 shows the measured DCF values and the neutron-to-total dose values (D_n/D_T) as measured both FIA and in the phantom MLT.

Summary

Determination of the MLT dose to the experimental subject is the primary objective for dosimetry measurements at AFRRI. The experimental design used during irradiation is reproduced as closely as possible during dosimetry measurements. For that reason, the appropriate phantom to be used for canine studies may be the AFRRI canine phantom. Its geometric positioning in the radiation field best duplicates the canine standing position during irradiation. Moreover, the phantom design more closely approximates the anatomical distribution of muscle tissue. Using this phantom, the investigator can choose the location (head, thorax, or abdomen) with its corresponding DCF value to arrive at the MLT dose that is appropriate for the biological endpoint.

The value of the D_n/D_T is important because it has been found that neutrons and gamma rays have significantly different RBEs for the type of canine irradiation experiments performed at AFRRI (12). The data in table 3 summarize the DCFs and the D_n/D_T values in the mixed neutron-gamma radiation fields used at AFRRI's TRIGA reactor.

Table 3. Averaged canine DCF and D_n/D_T values.

Phantom	DCF	D_n/D_T (MLT)
Cylindrical phantom*		
Midline	0.49	0.67
AFRRI phantom*		
Midthorax	0.70	0.66
Midabdomen	0.72	0.67
TNO phantom**		
Midthorax	0.78	0.74
Midabdomen	0.58	0.63

*All average values are based on measurements made between 1984 and 1992 (see table 1).
**The values are based on 1984 measurements.

It should be noted that the choice of phantom design can significantly influence the determination of the MLT dose. Table 3 clearly shows that the DCF used to determine the MLT dose at the point of interest—midabdomen—will yield greatly differing MLT doses depending on the phantom chosen to mimic the experimental conditions. If the results from the radiobiology research conducted at AFRRI are to be compared with those at other laboratories, a phantom design that is universal among the various laboratories should be chosen.

Acknowledgement

The authors thank the reactor staff for their support in dosimetry measurements. Special thanks go to Modeste Greenville and Carolyn Wooden for their assistance in the literature search and in preparing this report.

References

1. Attix FH (1986) Introduction to Radiological Physics and Radiation Dosimetry. New York: John Wiley and Sons

2. International Commission on Radiation Units and Measurements. Quantitative Concepts and Dosimetry in Radiobiology, ICRU Report 30, Washington DC; Apr 1979

3. International Commission on Radiation Units and Measurements. Determination of Absorbed Dose in a Patient Irradiated by Beams of X and Gamma Rays in Radiotherapy Procedures, ICRU Report 24, Washington DC; Sep 1976

4. Goodman LJ (1985) A practical guide to ionization chamber dosimetry at the AFRRI reactor. AFRRI Contract Report 85-1. Armed Forces Radiobiology Research Institute, Bethesda, MD

5. American Association of Physics in Medicine. Protocol for neutron beam dosimetry. AAPM Report No. 7 of Task Group 18, Fast Neutron Physics, Radiation Therapy Committee; 1980.

6. International Commission on Radiation Units and Measurements. Neutron Dosimetry for Biology and Medicine, ICRU Report 26, Washington DC; Jan 1977

7. Moore ML (1994) The TRIGA reactor facility at the Armed Forces Radiobiology Research Institute: A simplified technical description. AFRRI Technical Report 94-1. Armed Forces Radiobiology Research Institute, Bethesda, MD

8. Verbinski VV, Cassapakis CC, Hagan WK, Ferlic K, Daxon E (1981) Radiation field characterization for the AFRRI TRIGA reactor. DNA Report 5793F-1. Defense Nuclear Agency, Washington DC

9. Verbinski VV, Cassapakis CC, Hagan WK, Ferlic K, Daxon E (1981) Calculation of the neutron and gamma-ray environment in and around the AFRRI TRIGA reactor. DNA Report 5793F-2, Defense Nuclear Agency,Washington, DC

10. Ferlic KP, Zeman GH (1983) Spectrum-averaged kerma factors for reactor dosimetry with paired ion chambers. Technical Report TR83-2. Armed Forces Radiobiology Research Institute, Bethesda MD

11. Alderson RANDO phantom systems for radiotherapy. Technical Bulletin No. 43, Alderson Research Laboratories, Stamford, CT

12. MacVittie TJ, Monroy R, Vigneulle RM, Zeman GH, Jackson WE (1991) The relative biological effectiveness of mixed fission-neutron-γ radiation on the hematopoietic syndrome in the canine: Effect of therapy on survival. Radiation Research 128:529-536

13. Johns HE, Cunningham JR (1983) The Physics of Radiology. 4th ed. Springfield IL: Charles C. Thomas

Appendices

Appendix A
CHAMBER SENSITIVITY FACTORS

Chamber sensitivity factors are used in paired chamber equations to determine neutron and gamma doses in a mixed field of neutrons and gamma rays. The response of each ionization chamber to neutrons and gamma rays in a mixed radiation field is proportional to the chamber's calibrated response in a known gamma ray radiation field. The relative response of a calibrated chamber to neutrons and gamma rays can either be calculated or experimentally determined. In the expressions below, mathematical constants k_T, k_U, h_T, and h_U are used to calculate the responses (R_T or R_U) of the two chambers used simultaneously in a mixed field. Subscript T refers to the TE-TE chamber, which is sensitive to both neutrons and gamma rays, whereas subscript U refers to the Mg-Ar chamber that is mainly sensitive to gamma rays. The coefficients k and h respectively represent the neutron and gamma components of the doses, D_n and $D\gamma$. The readings described by R_T and R_U are the responses of each ion chamber in relation to how it responded in a known gamma radiation field.

$$R_T = k_T\ Dn + h_T\ D\gamma$$

$$R_U = k_U\ Dn + h_U\ D\gamma$$

As more knowledge was gained about the radiation fields in exposure room 1 during routine measurements for AFRRI's TRIGA reactor and through intercomparisons with the National Institute of Standards and Technology (NIST), the values used for k_T, k_U, h_T, and h_U changed slightly over the years in determining the canine DCF. Calculations show that changing the values used for k_T, k_U, h_T, and h_U will change the separate neutron and gamma doses that make up the total dose; however, the total dose will remain relatively unaffected. Therefore, the DCF values should and do remain consistent with each setup.

Appendix B
COMPOSITION OF TE LIQUID

The gamma spectral information for this field shows that the photoelectric effect is the dominating photon interaction (8, 9). Therefore, the effective atomic number (Z_{eff}) has a greater effect on the absorbed dose than does the mass density (ρ) of the absorbing medium (13). Results of the Z_{eff} calculations are 7.34 for the AFRRI TE liquid and 7.33 for the ICRU-recommended TE liquid (table 1).

Elastic scattering is the dominating mechanism for energy transfer from the neutrons in the energy ranges provided by the neutron spectral information (1). The interactions of the neutrons with the elements (hydrogen, carbon, nitrogen and oxygen) that make up the TE liquid must be considered. Using the average fluence-weighted neutron energy of 0.96 MeV (10), the average energy transferred per interaction ($\overline{E}_{tr}$) is approximated to be 0.128 MeV for the AFRRI TE liquid, 0.129 MeV for the ICRU TE liquid (1).

Table 1. Percent composition by weight and physical constants used for TE liquids.

	Hydrogen (%)	Carbon (%)	Nitrogen (%)	Oxygen (%)	Z_{eff} -	$\overline{E}_{tr}$ (MeV)	ρ (g/cm^3)
AFRRI TE liquid	10.24	11.20	3.65	74.66	7.34	0.128	1.06
ICRU TE liquid (without sucrose)	10.20	12.00	3.60	74.20	7.33	0.129	1.07

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Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 1996	Technical Report

4. TITLE AND SUBTITLE

Determination of Canine Dose Conversion Factors in Mixed Neutron and Gamma Radiation Fields

5. FUNDING NUMBERS

PE: NWED QAXM

6. AUTHOR(S)

Torres BA, Bhatt RC, Myska JC, Holland BK

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Armed Forces Radiobiology Research Institute
8901 Wisconsin Avenue
Bethesda, MD 20889-5603

8. PERFORMING ORGANIZATION REPORT NUMBER

TR96-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Uniformed Services University of the Health Sciences
4301 Jones Bridge Road
Bethesda, MD 20814-4799

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The primary objective of mixed-field neutron/gamma radiation dosimetry in canine irradiation experiments conducted at the Armed Forces Radiobiology Research Institute (AFRRI) is to determine the absorbed midline tissue dose (MLT) at the region of interest in the canine. A dose conversion factor (DCF) can be applied to free-in-air (FIA) dose measurements to estimate the MLT doses to canines. This report is a summary of the measured DCFs that were used to determine the MLT doses in canines at AFRRI from 1979 to 1992.

14. SUBJECT TERMS	15. NUMBER OF PAGES	16. PRICE CODE
	21	

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL